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RESEARCH MEMORANDUM

A FREE-FLIGHT INVESTIGATION AT ZERO LIFT IN THE MACH NUMBER RANGE BETWEEN 0.7 AND 1.4 TO DETERMINE THE EFFECTIVENESS OF AN INSET TAB AS A MEANS OF AERODYNAMICALLY RELIEVING AILERON HINGE MOMENTS

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

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RESEARCH MEMORANDUM

A FREE-FLIGHT INVESTIGATION AT ZERO LIFT IN THE MACH NUMBER RANGE BETWEEN 0.7 AND 1.4 TO DETERMINE THE EFFECTIVENESS OF AN INSET TAB AS A MEANS OF AERODYNAMICALLY RELIEVING AILERON HINGE MOMENTS

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SUMMARY

An experimental investigation employing a technique which utilized a zero-lift rocket-propelled model in free flight has been made to determine some of the characteristics of an inset tab as an aerodynamic balance in the Mach number range between 0.7 and 1.4. The fixed, 9-percent-chord, full-span, inset tab that was investigated was attached to a 30-percent-chord full-span aileron on a wing of aspect ratio 3 and taper ratio 0.6 that had the quarter-chord line sweptback 45° and NACA 65A006 airfoil sections parallel to the model center line. Results of this investigation show that the tab was capable of balancing (trimming) the aileron hinge moments throughout the Mach number range investigated even though the effectiveness of the tab decreased with increasing Mach number. It was shown that the aileron rolling effectiveness was decreased considerably when the tab was used to reduce the aileron hinge moments. The tab was an effective aerodynamic balance for Mach numbers less than 1.1; however, for approximately equal control hinge moments the aileron-tab combination was less effective than a narrow-chord aileron for Mach numbers greater than 1.2. At no time during the investigation did the mass-balanced aileron show any evidence of buzz or flutter. It was also shown that the tab effectiveness could be estimated with reasonable accuracy from experimental data and from thin-airfoil theory.

INTRODUCTION

As the speed of airplanes continues to increase, the problem of providing adequate power to overcome control hinge moments in order to obtain sufficient control becomes more acute. The disadvantages of

[redacted]

mechanical and hydraulic systems for multiplying the power that can be supplied by the pilot are becoming greater as the power requirements increase and the space available for the installation of a boost system decreases. An alternate way of approaching the problem would be to find some way of reducing the control hinge moments so that the need for a control boost system could be decreased or eliminated. The National Advisory Committee for Aeronautics has been engaged for some time in a program to investigate various methods of reducing control hinge moments with aerodynamic balances. Summaries of the experimental work that has been done on various aerodynamic balances at subsonic speeds and in the high-subsonic, transonic, and supersonic speed ranges are included in references 1 and 2, respectively. Results of a preliminary investigation of the effectiveness of several tab arrangements as aerodynamic balances in the transonic speed range are reported in reference 3.

As part of the aforementioned program, the Langley Pilotless Aircraft Research Division has completed a preliminary investigation with a zero-lift rocket-propelled model to determine the effectiveness of an inset tab as an aerodynamic balance in the Mach number range between 0.7 and 1.4 corresponding to a Reynolds number range of 3.4×10^6 to 9.5×10^6 (based on the mean aerodynamic chord of the wing). In this investigation, the rearward 30 percent of a full-span 0.3-chord aileron was given a deflection of 7.74° normal to the tab hinge line to form a fixed inset tab. The aileron was hinged along the 70-percent-chord line of a swept, tapered wing of aspect ratio 3 which had NACA 65A006 airfoil sections parallel to the model center line. The flight test was conducted at the Pilotless Aircraft Research Station at Wallops Island, Va.

SYMBOLS

b	wing span, ft
c	wing chord parallel to the model center line, ft
V	free-stream velocity, ft/sec
M	free-stream Mach number
p	model rolling velocity, radians/sec
$\frac{pb}{2V}$	wing-tip helix angle, radians
$\frac{pb}{2V}/\delta_a$	aileron rolling effectiveness parameter, radians/deg

$\frac{pb}{2V}/\delta_t$ tab rolling effectiveness parameter, radians/deg

α_p average angle of attack resulting from the rolling velocity, radians

q dynamic pressure, lb/ft^2

δ_a aileron deflection relative to wing-chord plane measured in a plane perpendicular to the aileron hinge line and normal to the wing-chord plane (positive when the trailing edge of left aileron, as viewed from rear, is down), average for two ailerons, deg

δ_t deflection of inset tab relative to aileron-chord plane measured in a plane perpendicular to the tab hinge line and normal to the aileron-chord plane (positive when trailing edge of left tab, as viewed from rear, is down), average for two tabs, deg

M' area moment of aileron (within basic wing plan form) rearward of the aileron hinge line, about aileron hinge line

C_h aileron hinge-moment coefficient,

$$\frac{\text{Aileron hinge moment about hinge of aileron}}{q2M'}$$

$$C_{h\delta_a} = \left(\frac{\partial C_h}{\partial \delta_a}\right)_{\alpha=0^\circ,\delta_t}$$

$$C_{h\delta_t} = \left(\frac{\partial C_h}{\partial \delta_t}\right)_{\alpha=0^\circ,\delta_a}$$

$$C_{h\alpha_p} = \left(\frac{\partial C_h}{\partial \alpha_p}\right)_{\delta_\alpha=\delta_t=0^\circ}$$

The subscripts outside the parentheses indicate the factors held constant during the indicated operation.

MODEL DESCRIPTION

The principal dimensions and external geometry of the model used in this investigation are shown in figures 1 and 2. The model consisted of a pointed cylindrical fuselage to which the wings and a cruciform tail were attached.

The fuselage, which was fabricated from wood and aluminum, contained a spinsonde (ref. 4) in the nose, telemetering equipment, and a 3.25-inch aircraft rocket motor. The cruciform tail attached to the rear of the fuselage was mounted so that it was free to rotate about the roll axis of the model.

The wing construction consisted of a laminated spruce core covered with a 0.040-inch-thick aluminum-alloy skin. This wing had an aspect ratio of 3.0, a taper ratio of 0.6, NACA 65A006 airfoil sections parallel to the model center line, 45° sweepback at the quarter-chord line, and full-span, constant 30-percent-chord ailerons. The ailerons, supported along the 70-percent-chord line with four hinges, were machined from magnesium alloy and were mass-balanced about the hinge line with a pressed-tungsten overhang. The ailerons were connected by a steel yoke (fig. 3) that straddled the rocket motor case so that each aileron would move through the same angle. Furthermore, the ailerons were arranged so they were free to float at the deflection which resulted in zero aileron hinge moment. Maximum aileron deflections were limited to approximately ±11° measured in a plane perpendicular to the aileron hinge line and normal to the wing-chord plane. The rear 0.3 chord of each aileron was deflected relative to the forward portion to form a fixed, full-span, inset, balancing tab. The tab deflection was 7.74° measured in a plane perpendicular to the tab hinge line.

TEST TECHNIQUE

The model, which was accelerated to a maximum Mach number of 1.4 by a two-stage propulsion system, was launched from a short rail launcher (fig. 4) that was inclined at an angle of approximately 70° above the horizontal. During flight, time histories of the flight-path velocity, rolling velocity, and the aileron floating angle obtained by radar, radio, and telemetry, respectively, were recorded at ground receiving stations. The time histories of these variables are shown in figure 5. These data, in conjunction with radiosonde measurements of atmospheric conditions encountered during the flight, permitted the evaluation of the aileron rolling effectiveness parameter $\frac{pb}{2V}\Big/\delta_a$ and the tab effectiveness parameter δ_a/δ_t in the Mach number range between 0.7 and 1.4.

The techniques used to obtain flight-path velocity and rolling velocity are further discussed in reference 5.

ACCURACY

The systematic errors in the measured aileron floating angles caused by the limitations of the measuring and recording systems and by excess play in the control system are estimated to be within $\pm 1^\circ$. The error in δ_t is estimated to be less than $\pm 0.06^\circ$. Other measured values are estimated to be accurate within the following limits:

	Subsonic	Supersonic
pb/2V, radians	± 0.005	± 0.004
M	± 0.010	± 0.005

RESULTS AND DISCUSSION

A portion of the actual telemeter record obtained between $M = 0.95$ and $M = 1.05$ is presented in figure 6. The trace on the record indicates the aileron floating angle as a function of time. It is significant to note that at no time during the flight did the trace on the telemeter record give any indication that the free-floating mass-balanced ailerons were subject to buzz or flutter.

Experimental results of this investigation showing the variation of the aileron floating angle and the wing-tip helix angle with Mach number are presented in figure 7. The aileron floating angle, which is the angle the aileron assumed for the sum of the moments about the aileron hinge line to equal zero, decreased with increasing Mach number, thus indicating that the effectiveness of the fixed inset tab as an aerodynamic balance decreased as the Mach number increased. However, included in the apparent reduction in tab effectiveness is a decrease in the relatively small balancing effect obtained from the angle of attack due to rolling. The decrease in this small balancing effect resulted primarily from the decrease in pb/2V with increasing Mach number.

Presented in figure 8 is a curve determined from the results of this test showing the manner with which the aileron-deflection—tab-deflection ratio needed for zero aileron hinge moment varied with Mach

number. From

$$\frac{\delta_a}{\delta_t} = - \frac{C_{h_{\delta_t}}}{C_{h_{\delta_a}}} - \frac{C_{h_{\alpha_p}}}{C_{h_{\delta_a}}} \frac{\alpha_p}{\delta_t}$$

it can be seen that, for the small values of α_p obtained in this investigation, $\frac{C_{h_{\alpha_p}}}{C_{h_{\delta_a}}} \frac{\alpha_p}{\delta_t}$ becomes very small and the ratio δ_a/δ_t indicates the effectiveness of the tab. Therefore, it can be seen in figure 8 that the tab effectiveness decreased with increasing Mach number until at $M = 1.4$ the tab was approximately 60 percent as effective as it was at $M = 0.7$. However, it is apparent from this test that the moments about the aileron hinge line for a constant aileron deflection could be balanced at any particular Mach number by selecting the proper value of δ_a/δ_t.

Values of δ_a/δ_t estimated from the experimental aileron rolling effectiveness results presented in reference 6 are also included in figure 8. The experimental results used from reference 6 were obtained for models with three wings of aspect ratio 4, each with fixed, full-span ailerons. No attempt has been made to apply any correction for any difference that may be due to the number of wings; however, a correction for the difference in aspect ratio has been applied by an, as yet, unpublished method. These models had wings comparable in stiffness to those of the present investigation; the maximum loss in rolling effectiveness was approximately 20 percent of the rigid-wing values throughout the Mach number range of these tests. In this analysis, the assumption was made that control lift force on a wing-control combination is proportional to the $pb/2V$ per unit control deflection developed by that combination. Hence, it was possible to calculate the value of δ_a/δ_t necessary for zero aileron hinge moment, first, by estimating with the aid of reference 6, values of $\frac{pb}{2V}/\delta_a$ for a wing-control combination having a control chord equal to the test aileron chord less the inset-tab chord; second, values of $\frac{pb}{2V}/\delta_t$ were estimated for a wing-control combination where the inset tab was considered to be the only control. Then the moments about the aileron hinge line resulting from these lift forces and the distances to appropriate center-of-pressure locations, based on available but as yet unpublished data on various flap and tab loadings, were summed and set equal to zero. Values of δ_a/δ_t that were calculated in the foregoing manner show fair agreement with the experimental results obtained from this test throughout the Mach number range investigated.

Empirical data in reference 1 were used to calculate a subsonic value of δ_a/δ_t. This value, which is shown in figure 8 for $M = 0.7$, agrees well with the experimental value at this Mach number.

The points at $M = 1.67$ and $M = 1.94$ in figure 8 are the results of two methods that were used to calculate supersonic values of δ_a/δ_t at the lowest Mach numbers at which the particular methods could be applied. Thin-airfoil theory was used to calculate the δ_a/δ_t value shown at $M = 1.67$ by assuming two-dimensional supersonic flow over a thin-plate airfoil-aileron-tab combination and using oblique shock compression and Prandtl-Meyer expansion formulas from reference 7 to obtain pressure differences over the aileron and tab surfaces. Values of the rate of change of aileron hinge moment with aileron deflection and angle of attack for the aileron-tab combination, determined from reference 8, were used to calculate the value of δ_a/δ_t shown at $M = 1.94$. After extrapolating the experimental results obtained during the present test (assuming only a small loss in tab effectiveness with increasing Mach number) it can be seen that the calculated values of δ_a/δ_t at $M = 1.67$ and $M = 1.94$ would be of the same order of magnitude as the extrapolated values.

The probable penalty incurred throughout the Mach number range investigated from using the inset tab to balance the aileron hinge moments can be noted in figure 9 by comparing the aileron rolling-effectiveness values obtained during the present test with the aileron-rolling-effectiveness values estimated from reference 6 for the same wing with a 0.3c aileron and no tab. The loss in aileron rolling effectiveness due to the inset tab was nearly constant throughout the Mach number range investigated and amounted to approximately 75 percent at $M = 1.4$.

The experimental results presented in reference 6, corrected for the difference in aspect ratio, were also used to estimate the aileron effectiveness of a wing-aileron-tab configuration similar to the model employed in this investigation. These estimated rolling-effectiveness values, as shown in figure 9, agree very well with the experimental results obtained during the present test throughout the Mach number range investigated.

In figure 10, a comparison is made between the $\frac{pb}{2V}/\delta_t$ values obtained for the aileron-tab combination employed in the present investigation and those estimated from the results of reference 6 for a similar configuration except that $\delta_a = 0^\circ$, which corresponds to a configuration having 0.09c tabs that served as narrow-chord ailerons. This comparison shows that, for equal tab deflections (approximately equal tab hinge moments), greater rolling effectiveness was obtained by the aileron-tab

combination at speeds up to approximately $M = 1.1$. However, after a period of about equal rolling effectiveness (ending at $M \approx 1.2$) greater rolling effectiveness was obtained by the configuration with the 0.09c tabs that served as narrow-chord ailerons.

CONCLUSIONS

The results of an investigation made in the Mach number range between 0.7 and 1.4 with a technique that utilized a zero-lift rocket-propelled model to determine the effectiveness of a full-span inset tab as a device for reducing aileron hinge moments of a full-span 0.3-chord aileron on a wing of aspect ratio 3 and taper ratio 0.6 that was sweptback 45° along the 0.25-chord line and that had NACA 65A006 airfoil sections parallel to the model center line indicate the following conclusions:

1. The tab was capable of balancing (trimming) the aileron hinge moments throughout the Mach number range investigated.

2. The balancing effectiveness of the tab decreased with increasing Mach number throughout the Mach number range investigated.

3. The aileron rolling effectiveness was decreased considerably by the presence of the tab throughout the Mach number range investigated.

4. The tab was an effective aerodynamic balance for Mach numbers less than 1.1; however, for approximately equal control hinge moments the aileron-tab combination was less effective than a narrow-chord aileron for Mach numbers greater than 1.2.

5. There was no indication that the aileron, which was mass-balanced, was subjected to buzz or flutter at any time during the test.

6. It appears possible to estimate the effectiveness of an inset tab of the particular configuration tested from experimental data and from thin-airfoil theory.

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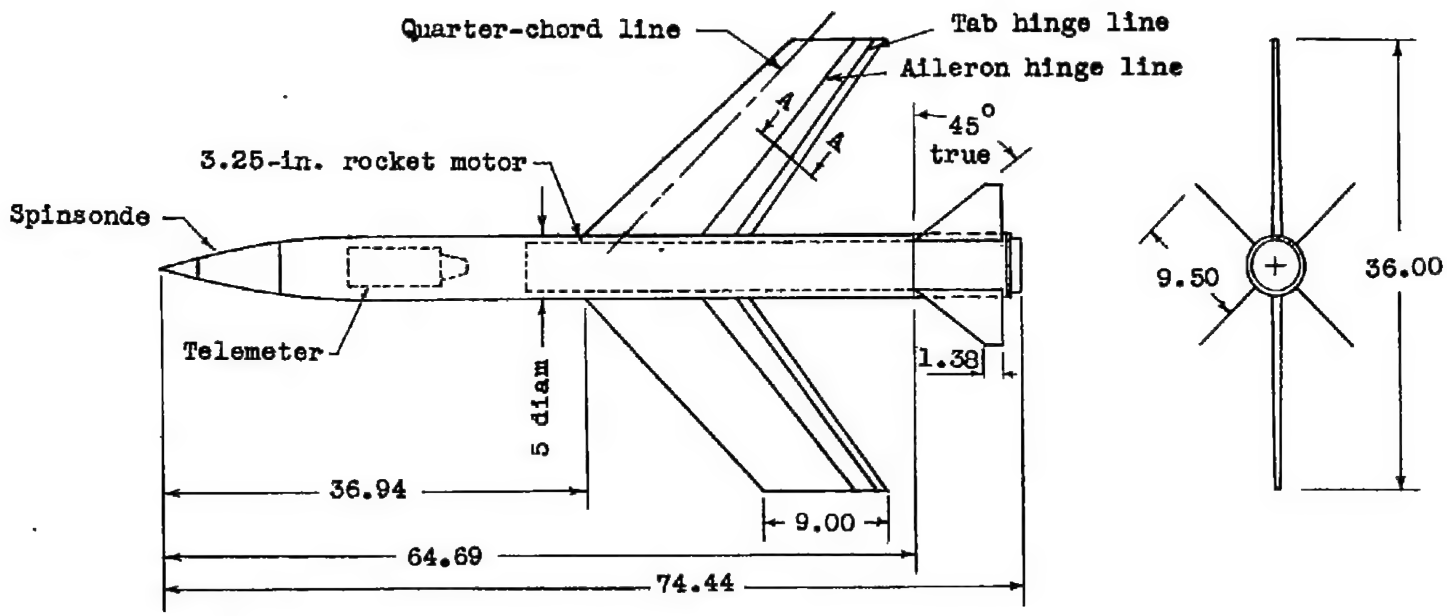

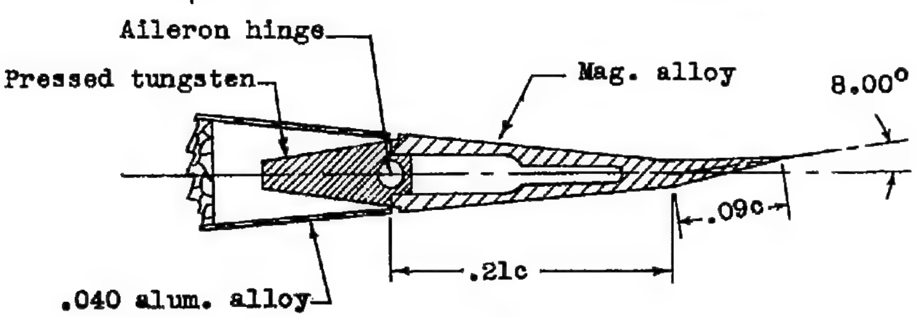

Section A-A
normal to aileron hinge line

Wing Data

Aspect ratio	3.0
Taper ratio	.6
Included area	432 sq in.
Airfoil	NACA 65A006
Sweepback of the quarter-chord line	45.00°
Sweepback of the aileron hinge line	40.35°
Sweepback of the tab hinge line	37.98°

Figure 1.- General arrangement of model and detail of aileron. All dimensions are in inches.

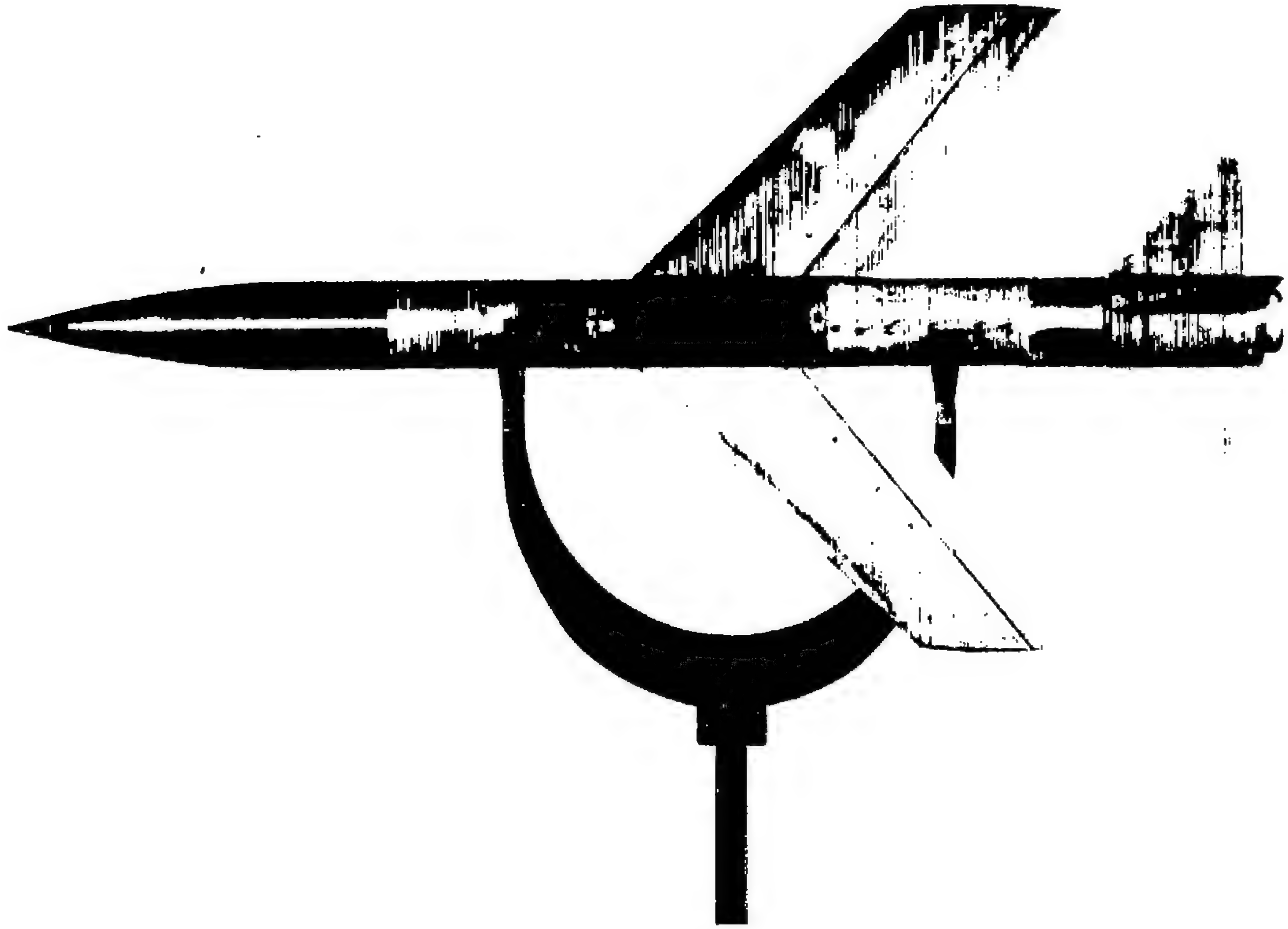

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Figure 2.- Model used in this investigation.

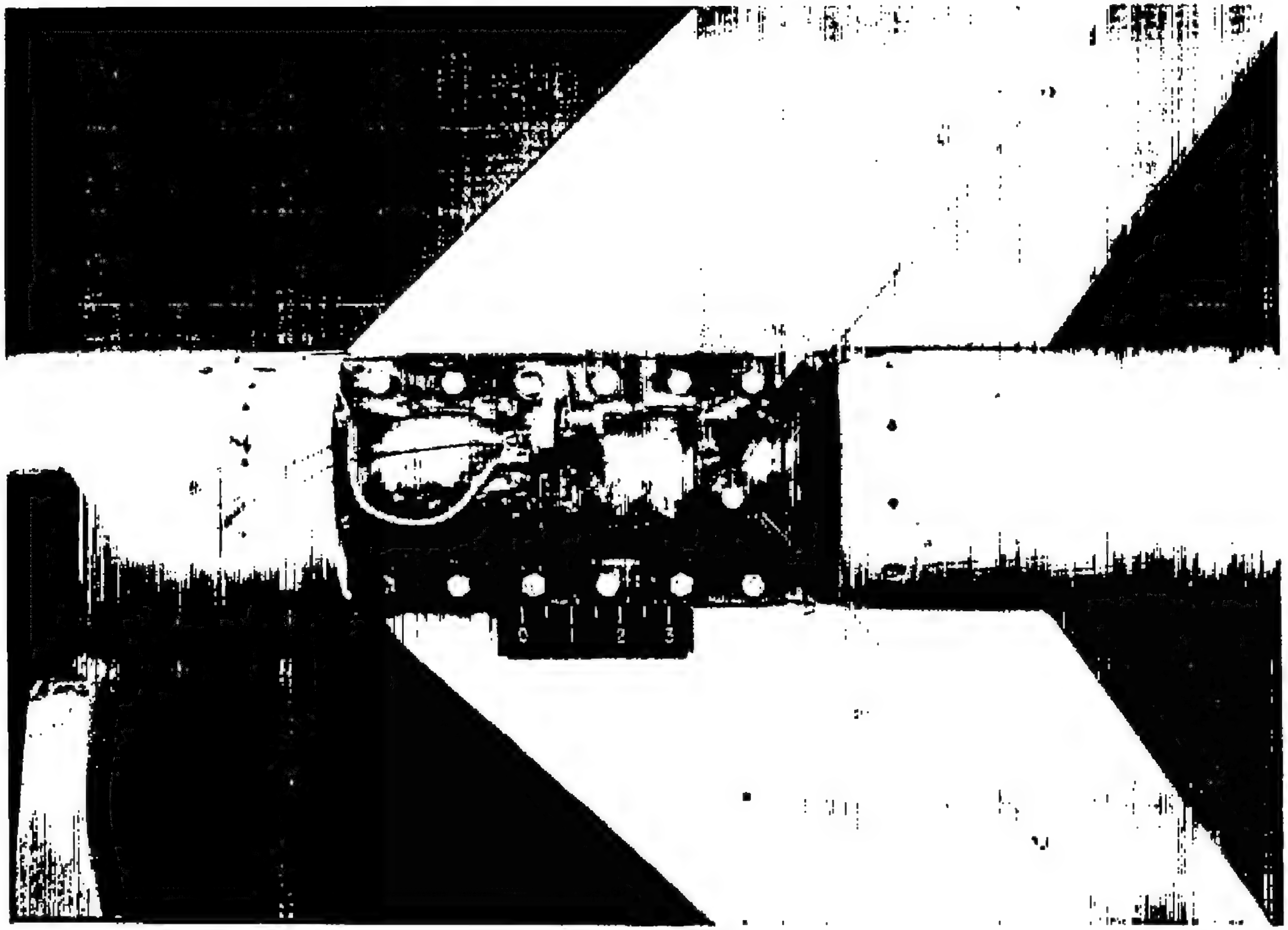

Figure 3.- Double exposure of model showing the positions of the aileron connecting yoke for the two extreme aileron deflections. NACA L-74022.1

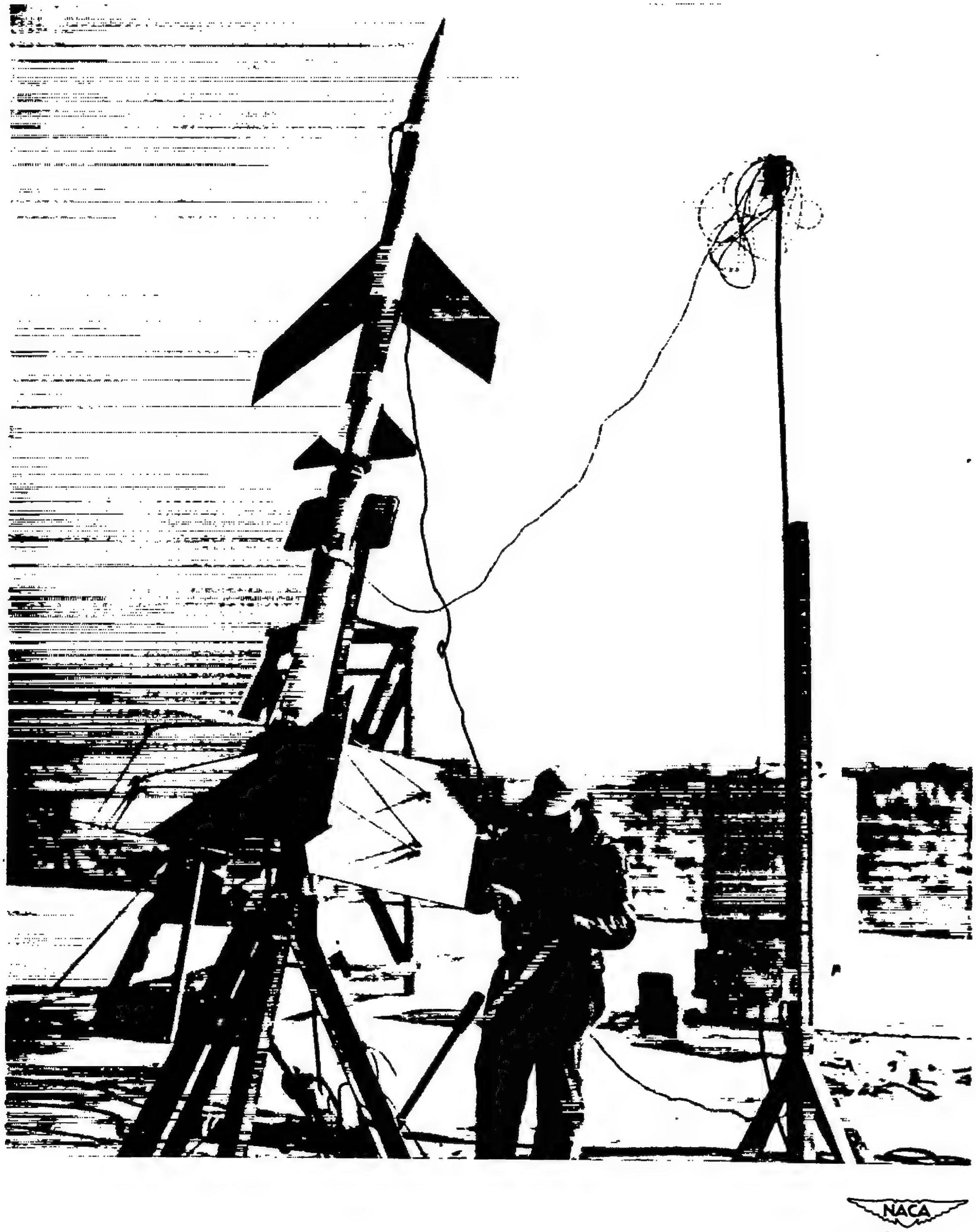

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Figure 4.- Photograph of model and booster rocket motor assembly on launcher.

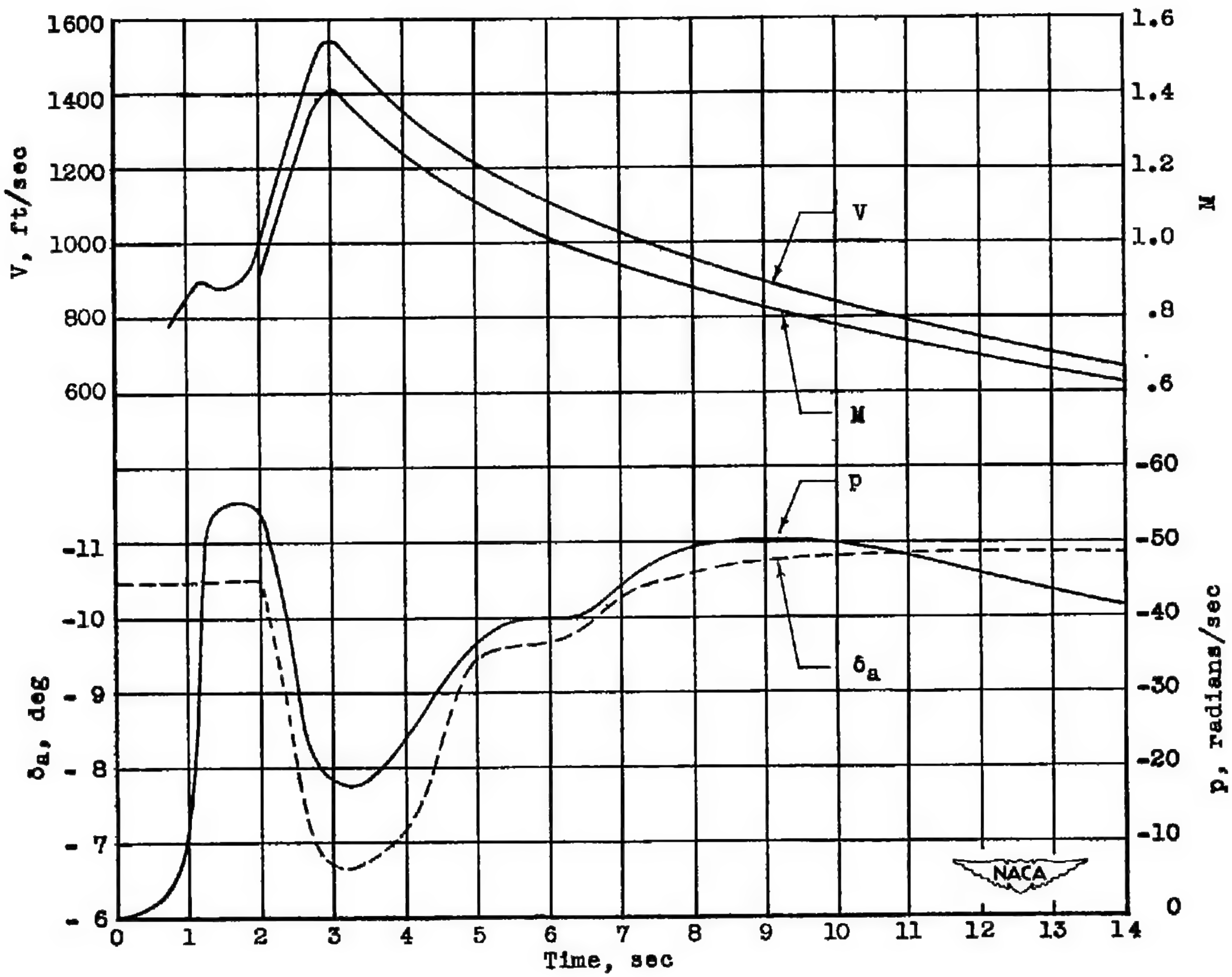

Figure 5.- Time histories of flight-path velocity, rolling velocity, aileron floating angle, and Mach number.

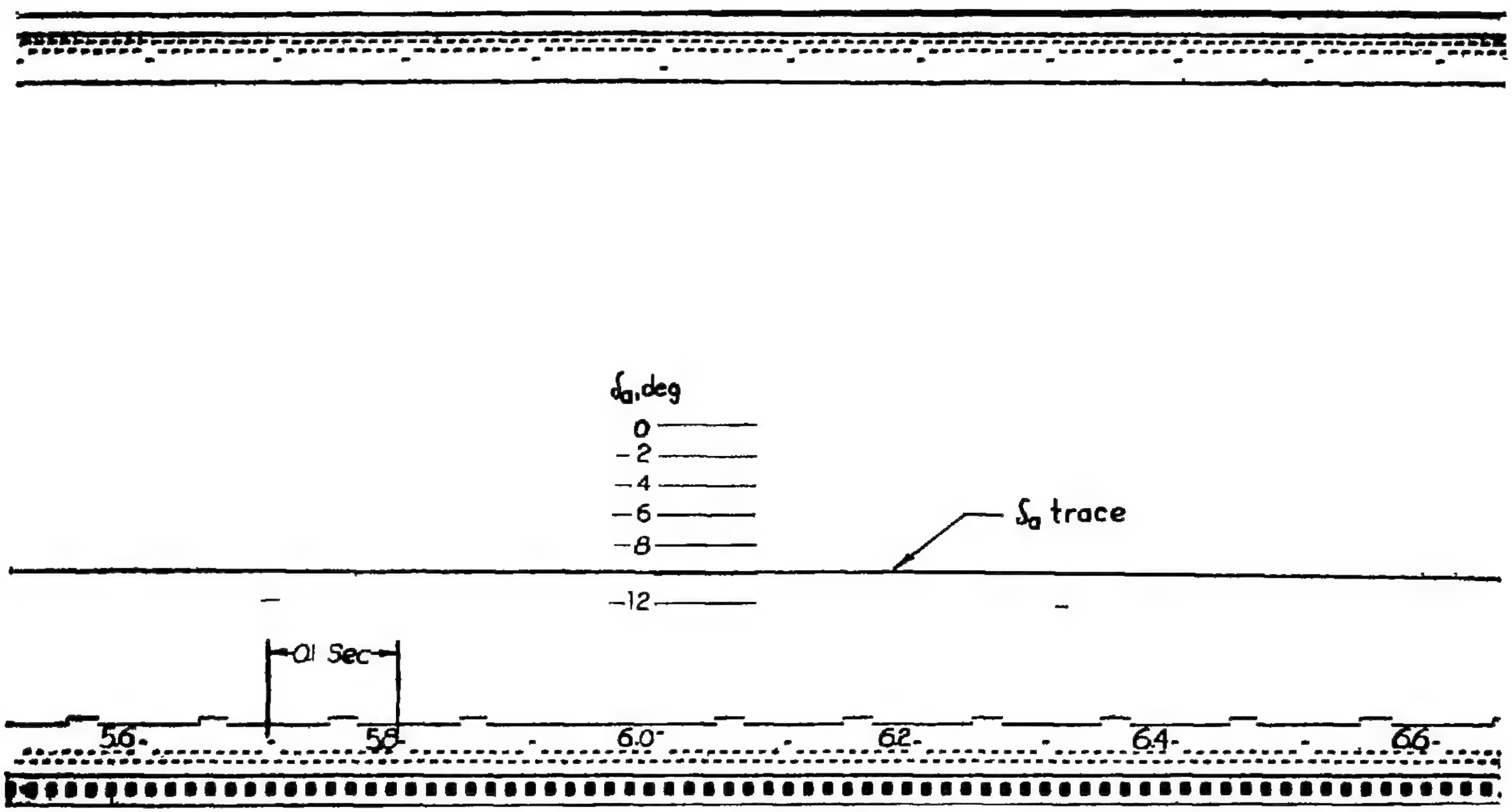

Figure 6.- Portion of telemeter record obtained during flight between M = 0.95 and M = 1.05.

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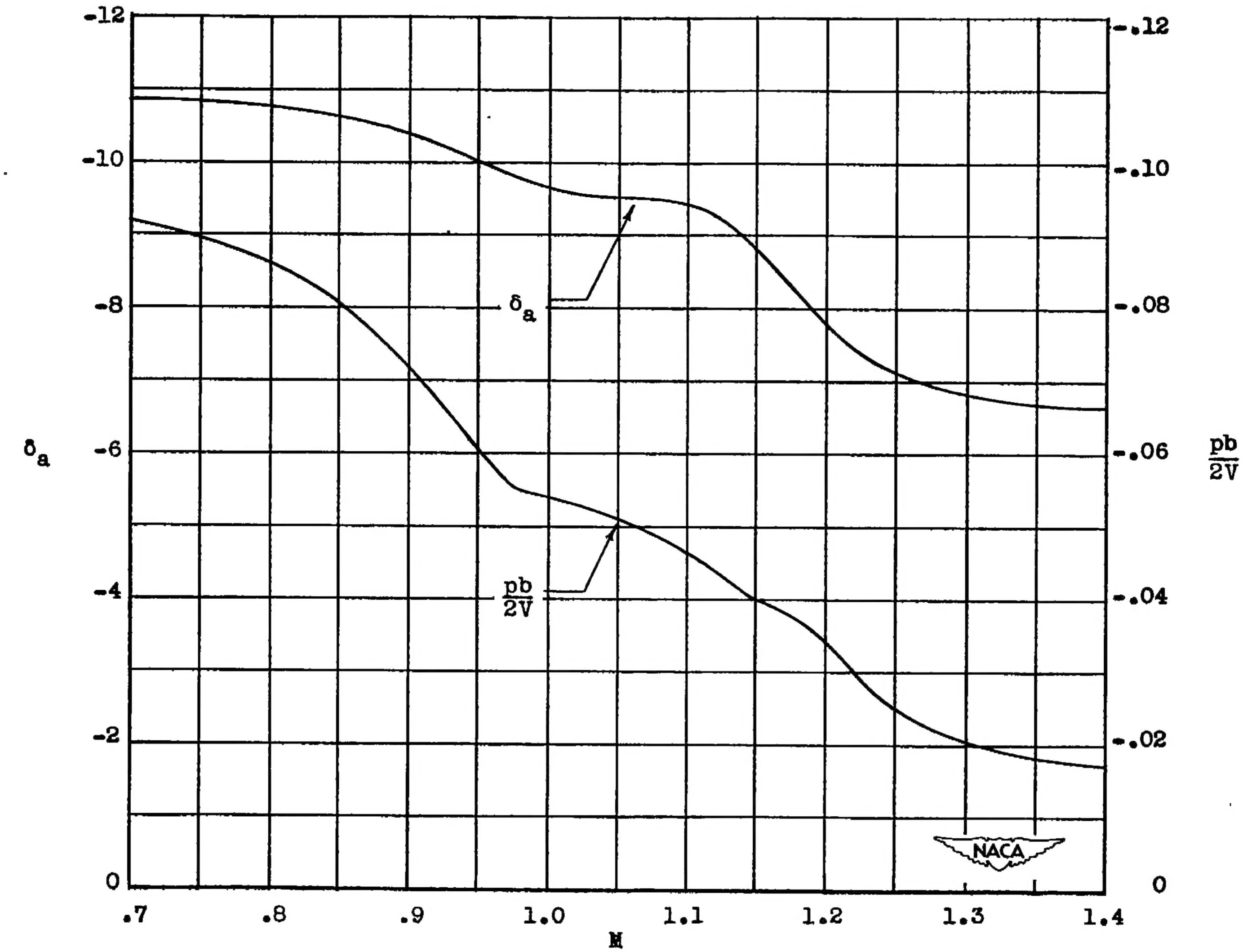

Figure 7.- Variation of the aileron floating angle and the wing-tip helix angle with Mach number.

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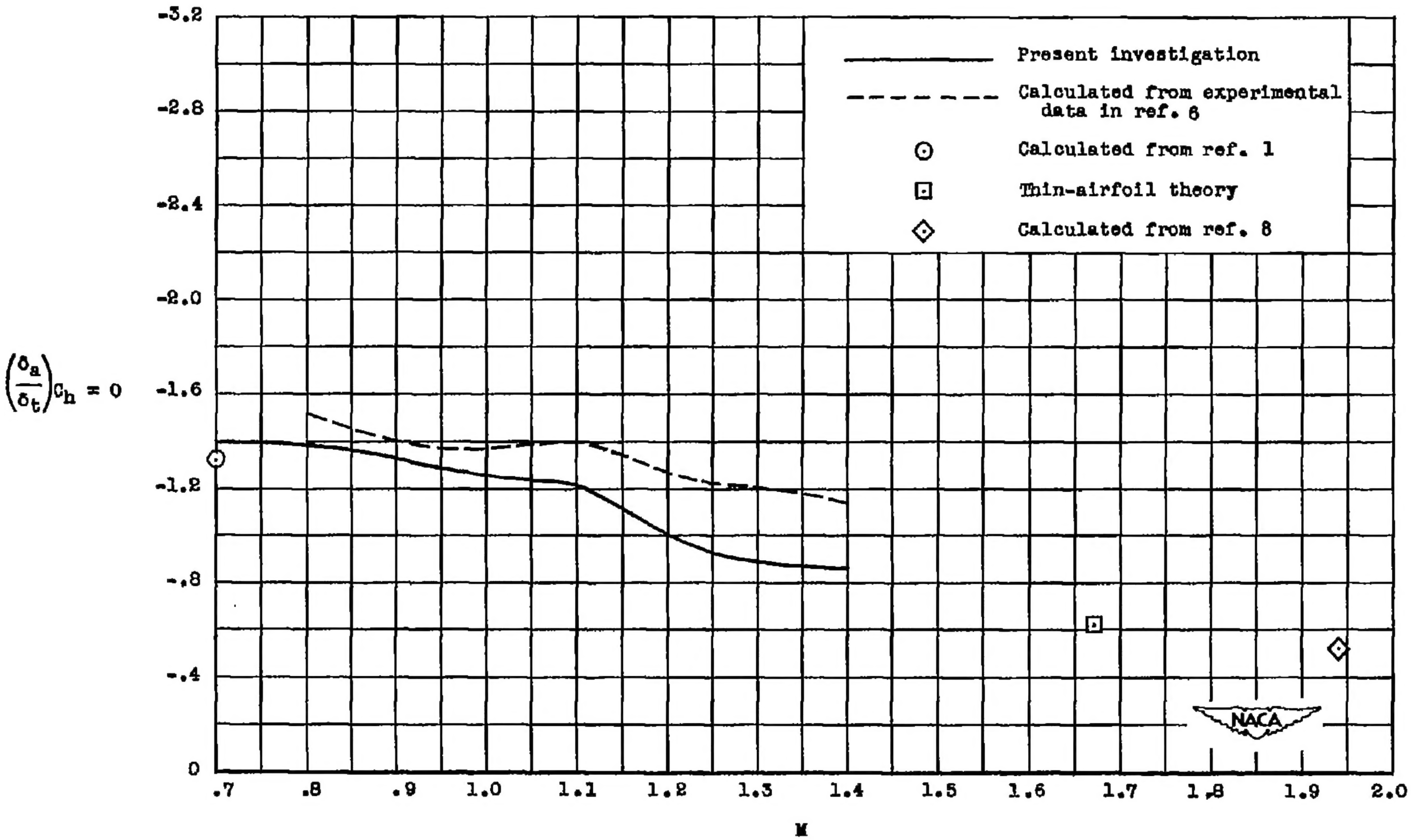

Figure 8.- Variation of the aileron-tab deflection ratio for zero aileron hinge moment with Mach number.

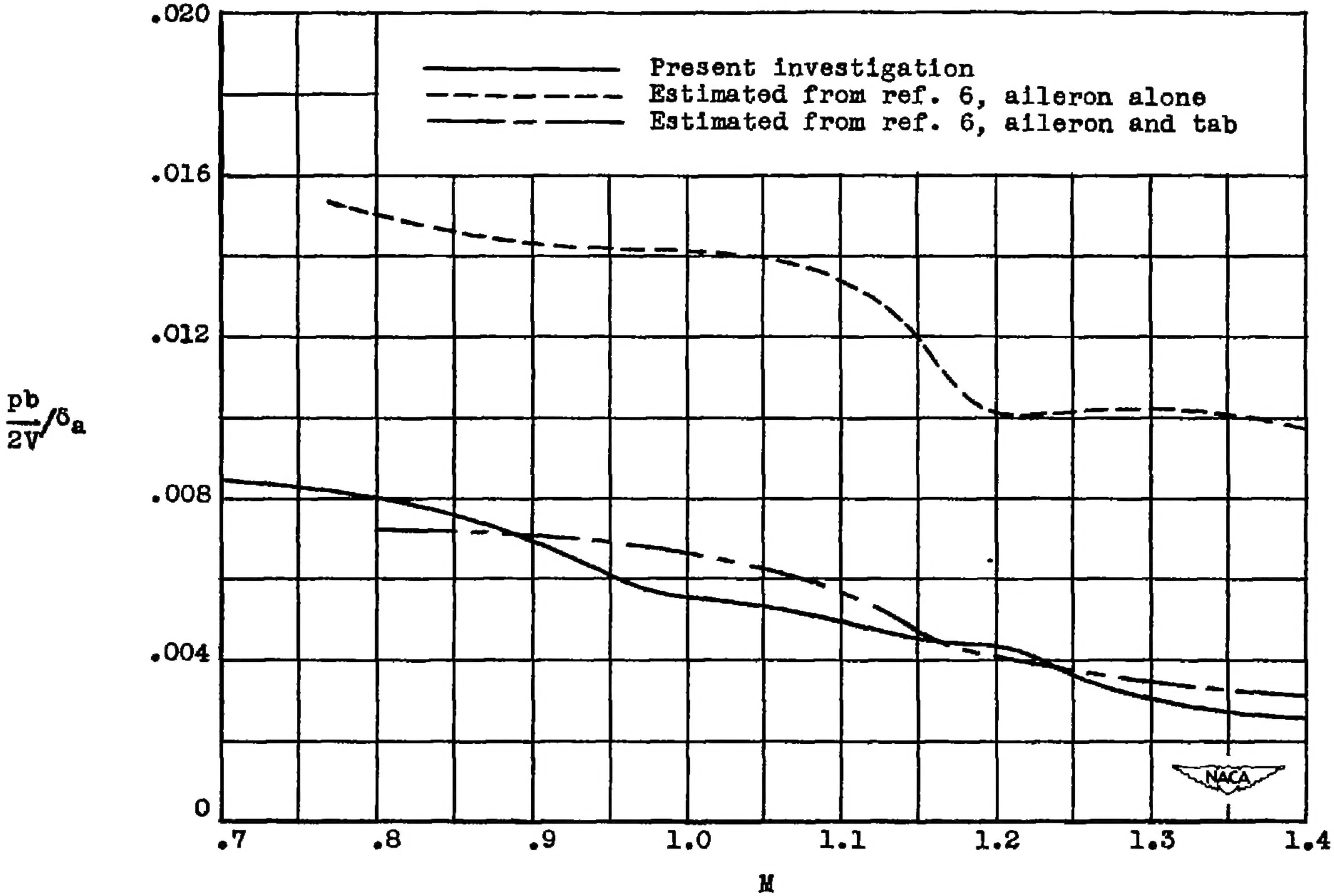

Figure 9.- Variation with Mach number of the aileron-rolling-effectiveness values from the present investigation and as determined from the data of reference 6.

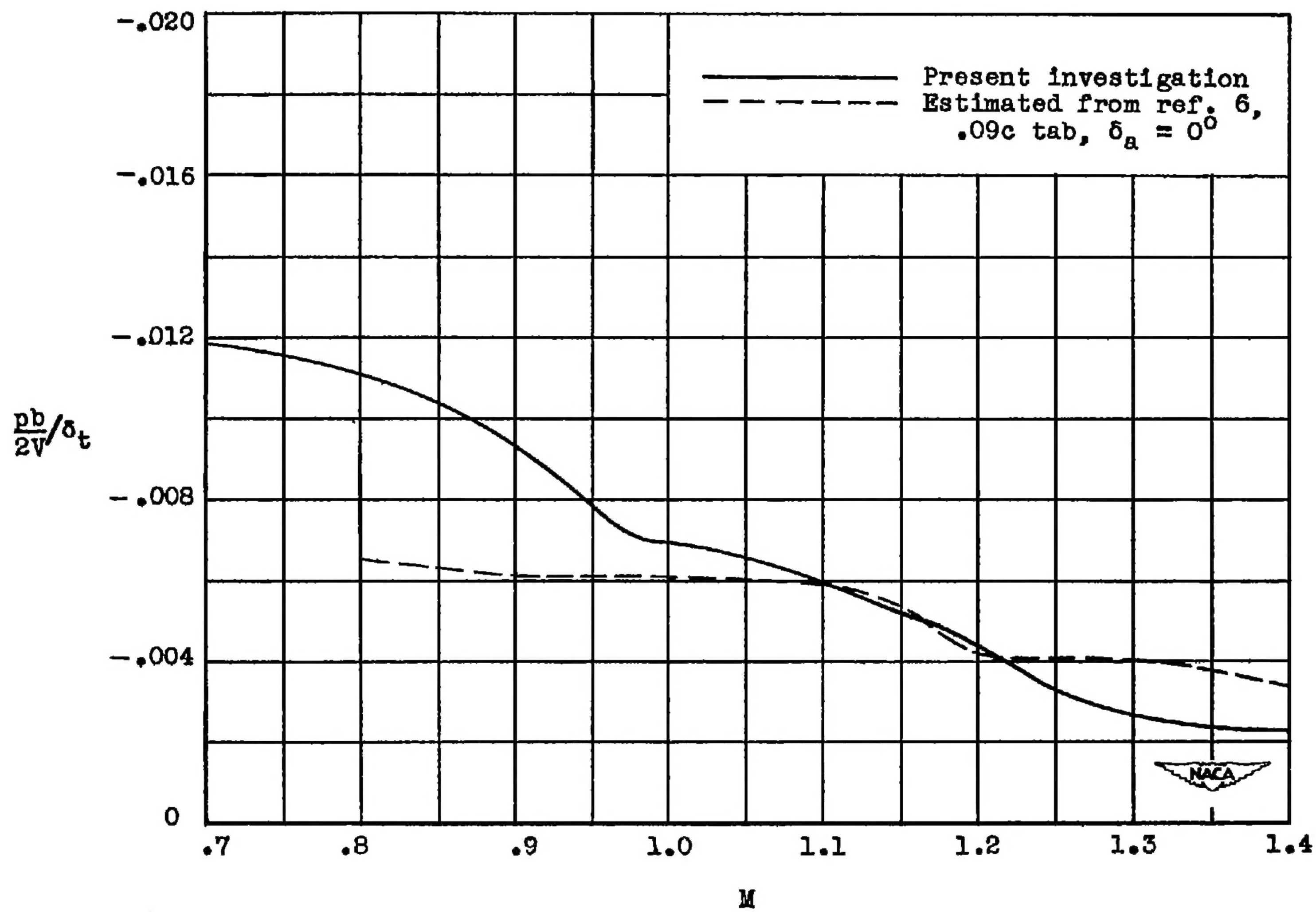

Figure 10.- Variation with Mach number of the rolling-effectiveness parameter per degree of tab deflection obtained from the present investigation and as estimated from reference 6 for a configuration with 0.09c tabs that served as ailerons.